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MODULATED-LIGHT FILM-VIEWING SYSTEM STUDY

FINAL REPORT

Prepared by the

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Issued: March 4, 1965

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PREFACE

This is the final report for the "Modulated-Light Film Viewing Study," prepared by the [redacted] This report covers the work performed from July 15, 1964 to January 15, 1965. 25X1

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The principal author for this report is [redacted] 25X1

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SECTION I
INTRODUCTION

A. GENERAL

The objective of this study program was to attain the necessary knowledge to formulate a design for a modulated-light film-viewing system. This report describes the theoretical and experimental investigations which were undertaken in a study of applicable techniques that would lead to a workable system.

The background of the problem is presented in this section along with a description of the type of modulated-light film-viewing equipment that is understood to be needed by the customer. Following this, in Section II, the program requirements are outlined and the technical approach described. Results and recommendations are presented in Section III on several techniques that were studied in varying degrees of detail, including that combination of techniques that was deemed to provide a useful and relatively inexpensive system. A summary of the conclusions of this study is given in Section IV.

B. BACKGROUND

In photo-interpretation, one of the most necessary and basic pieces of equipment is the direct-viewer light table. In general, the light tables are illuminated by fluorescent tubes with continuously variable intensity. Although this method of illumination fulfills its basic purpose as a light source, a more sophisticated, modulated-light system would improve the intelligence retrieval process in two ways: it would reduce the physiological strains involved for the human visual system, and it would enhance the display of photographic information for more effective exploitation.

With current methods of illuminating transparencies, there is no way to mask extraneous light, and there is no way to attenuate light under thin densities while providing adequate light under heavy densities. When searching for details in the dense regions of a transparency, the eye is affected because the iris closes down in the presence of flare either surrounding the transparency or passing through adjacent thin-density areas. Particularly difficult visual situations are presented by snow, clouds, shadows, and occasionally, haze.

A modulated-light film viewer would provide a means of viewing transparencies either directly or by projection and would provide a means of modulating the illuminating source from point to point, depending on the particular densities of the transparency being viewed. In addition, the modulated light could be used to produce special effects, such as contrast compression, contrast stretch, selective masking, and perhaps other enhancement effects that have not yet been fully investigated.

From the information in the request-for-proposal, and from discussions with technical personnel representing the supporting agency, the modulated-light film-viewing equipment needed can be typified as follows:

1. A small, flexible, modulated-light table for direct-viewing of film to replace or supplement the existing 9- × 18-inch fluorescent table now in use. The principal use of these tables was understood to be routine inspection of roll film with the naked eye or with low-power magnification.

2. A larger table for more detailed directly-viewed inspection of film under higher magnification than used in the small table (9- × 40-inch tables are currently in use). Since the photo-interpreter must frequently work with small images of low relative contrast, enhancement of the visibility of these features is desirable in addition to the reduction of large-area contrast.

3. Rear-projection viewers.*

C. SUMMARY AND CONCLUSIONS

The principal effort in this study was directed toward the investigation and development of techniques for contrast compression in broad areas. As a result of theoretical and experimental investigation, a system based on direct illumination provided by a television kinescope, i.e., placing the film in contact with the kinescope faceplate, has been recommended for initial equipment development. Investigations were also made of the applicability of photochromism techniques, a method of scanning with a light beam generated by a source other than a cathode-ray tube, and the technique of providing illumination by a projection-television system. It was found that neither the photochromism nor the scanning-light-beam techniques were suitable, and the projection television system did not compare favorably with the directly viewed CRT system.

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* In accordance with the conditions set forth in the work statement, rear-projection viewers were to be an area of secondary investigation.

SECTION II
SYSTEM REQUIREMENTS AND TECHNICAL APPROACH

A. SYSTEM REQUIREMENTS

The basic requirements for a directly viewed modulated-light table were outlined in the specification as follows:

1. Illumination of up to 1000 foot-lamberts with 2000 foot-lamberts desirable.
2. The modulation of the illumination to be inversely proportional to the transmittance of the film.
3. The modulation of the illumination to be directly proportional to the spatial-frequency content of the film.
4. The size and position of the modulated-light region shall be independently controllable.
5. Visually perceptable flicker or smear (on the moving film) are not permitted.
6. Spurious effects resulting from unidirectional scan are not permitted.

B. TECHNICAL APPROACH

Photochromic materials, a scanning-light beam, and projection and directly viewed CRT systems were considered for this application. The results of investigations of both the photochromism technique and the scanning-light beam method were unsatisfactory. Consequently, the principal effort in this study was directed toward a system utilizing the cathode-ray tube concept. The investigations of non-CRT systems that led to this decision are described in detail in Section III.

Two types of CRT scanning systems were considered: a directly viewed CRT in which the film is in contact with the faceplate, and a projection system in which light from the CRT is imaged onto the film plane. The principal virtue of the former is simplicity; the latter is noteworthy in that it can provide additional operational capabilities, albeit at the expense of greater bulk and cost. Following detailed investigations of each of the systems, the relative merits and costs were compared. Based on this comparison, the system of direct illumination provided by a CRT is recommended for initial equipment development.

SECTION III
SYSTEM STUDIES

A. GENERAL

Four modulated-light film-viewing techniques were investigated in the course of this study: (1) directly viewed CRT, (2) projection-viewed CRT, (3) scanning-light beam, and (4) photochromism. The results of each of the investigations are described in this section. It should be noted that the discussions that follow have been organized into topics and are not presented in the chronological order in which the studies were performed. Of the two CRT systems, the projection-viewed CRT system was investigated first. When it became apparent that sufficient illumination could not be achieved with this system without very high-powered components and a special Schmidt optical-system design, a directly viewed CRT system was investigated with such results that the latter system was selected for investigation and subsequent recommendation for initial equipment development.

A summary comparison of the two systems precedes the detailed system discussions. This summary, presented in tabular form, highlights the advantages offered by the directly-viewed CRT system for application in the small light table.

SUMMARY COMPARISON OF DIRECTLY VIEWED AND PROJECTION-VIEWED CRT SYSTEMS

Feature	Directly Viewed System	Projection System
Size of display	9 × 9 to 9 × 18 inches	9 × 9 to 9 × 12 inches
Peak brightness	1000 ft-lamberts	1000 foot-lamberts
Spot size	Relatively large minimum	Can be made small
Illuminated surface shape	Cylindrically curved, convex. Spot size will be larger if made flat.	Flat
Flexibility of attitude	Can be made to tilt and rotate	Can be made tiltable, but cumbersome to rotate.
Size of equipment	Can be made reasonably compact	Relatively large
Cost	About 50% of that for projection equipment.	

B. DIRECTLY VIEWED CRT SYSTEM

In the directly viewed CRT system, the film is placed in contact with the faceplate of the cathode-ray tube. Preliminary investigations of this type of system were begun using a flat-faced five-inch CRT. Initial results with respect to contrast compression and brightness were sufficiently encouraging that the customer requested [redacted] to arrange a breadboard demonstration on a larger scale.

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1. Breadboard Experiments

The breadboard model utilized a 10SP4 kinescope,* deflection circuitry, amplifiers, photomultiplier pickup, and power supplies.** The kinescope was mounted on a box with a glass front, which was, in turn, mounted on a table. The box was tiltable to a convenient viewing angle. Optical feedback pickup was accomplished by a photomultiplier tube placed in a position to be over the observer's shoulder. Controls were provided for brightness (by controlling kinescope cathode potential) and modulation gain (by controlling photomultiplier supply voltage). The modulation signal was applied to the control grid of the CRT. Standard commercial television scanning rates were used (525 lines, 60 cps, interlaced 2 to 1). A diffuser was required between the kinescope faceplate and the film transparency to avoid parallax which would otherwise arise from the different viewing angles of the observer and the photomultiplier pickup, because of the thickness of the faceplate. The use of the diffuser in this configuration results in a minimum spot size which is about the size of the thickness of the faceplate. Methods for reducing the spot size have been considered and are described later in this section. A raster of about 6- by 6-inches was scanned. No provision was made for reducing the illuminated area, because the deflection circuitry was not readily adaptable to size change. It should be noted, however, that circuitry designed for this application could be made to operate with reduced raster, and in fact, this was done. This work is described in a later section.

Measurements were made of contrast compression with the breadboard arrangement described above. The test chart consisted of a set of neutral-density filters, overlapped to give densities of 0, 0.3, 0.7, 1.0, 1.7, and 2.0. Brightness measurements with and without feedback were made using a Spectra Pritchard photometer having a $1/2^{\circ}$ field of view. Results are plotted in Figure 1; the two feedback

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* A truly flat-faced kinescope in a large format is not commercially available. The 10SP4 has a spherical faceplate with a 42-inch radius of curvature. The Rauland Company makes a large kinescope with a spherical faceplate having a 140-inch radius of curvature.

** The deflection circuitry, amplifiers, photomultiplier pickup, and power supplies were designed and built for the projection-CRT system. When effort was redirected toward the directly viewed system, this equipment was modified, as required, and incorporated into the breadboard model described above.

curves were obtained using the same gain setting but different brightness-level settings. It should be noted that the circled point in Figure 1 represents a brightness of 1200 foot-lamberts on the illuminated side of the film.

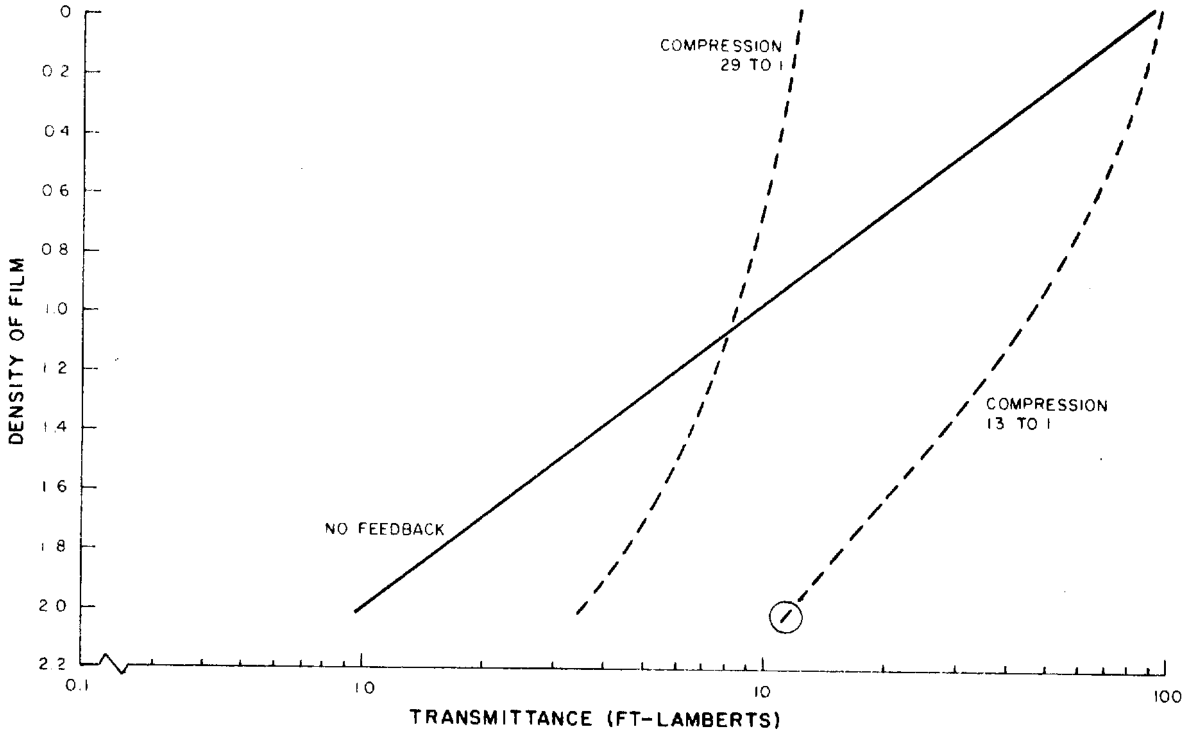

Figure 1. Measured Performance of the Breadboard Directly Viewed CRT System

The contrast-compression effect achieved by the breadboard has been subjectively evaluated by several observers, including [redacted] specialists in optical science and photography, and by two customer representatives. Various types of aerial photographs and test charts were used as test media. The consensus was that considerable improvement in ease of viewing resulted for high-contrast photographs, such as those containing clouds and cloud shadows. Reduction of unwanted shading, such as from vignetting, was also noted. As might be expected, the improved viewing conditions were less marked for medium-contrast targets, and all but nonexistent for low-contrast targets. For the high-contrast targets, the improvement in recognizability of features occurred principally in regions of high- and low-transparency, and in regions adjacent to large areas of high transparency, with some reservations about the quality of improvement in the last case because of the question of spot size. 25X1

The presentations were also evaluated with magnified viewing using a [redacted] 7X-30X Stereozoom microscope. Improvement of viewing ease, and in some cases of detail recognizability, was noted for high-contrast targets, particularly in the vicinity of deep shadows and bright highlights. Some improvement in detail recognizability seemed to result even in a medium-contrast, low-level, low-angle photograph of Philadelphia, where it appeared that features in building shadows and the interior of a building under construction were enhanced. 25X1

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A test pattern having 36 steps with transmittance ratios of $\sqrt[4]{2}$ was viewed with the breadboard equipment. Without feedback no more than 27 steps were discernible, but all 36 could be discerned with feedback. A maximum of 31 steps could be seen when viewed with bright-sky illumination.

Some negative reaction to the breadboard presentation was produced by the following effects:

1. Visible flicker, which was expected because of the use of a standard television scanning rate and could be corrected by the use of the specifically designed scanning system, described in Paragraph B.2 of this section.

2. Too large a spot size for some viewing conditions. In magnified viewing, the large spot size resulted in decreased contrast compression relative to the compression in areas of the same apparent size when viewed without magnification. In regions immediately adjacent to large areas which were very opaque or transparent, the illumination was higher, or lower, respectively, than it should be. The possibilities for reducing spot size are discussed in Paragraph B.3 of this section.

3. Placement of the photomultiplier pickup over the observer's shoulder. Subsequently, the photomultiplier was placed behind the plane of the film on one side of the CRT enclosure, and light was fed into it by means of a Lucite light guide. The light guide consisted of an isoceles triangle, cut from 1/2-inch-thick Lucite, having a base of about 6 inches and a height of about 12 inches. A 90° bend was made about 2 inches above the base, and the apex was truncated to fit the face of the photomultiplier. The base of the guide-funnel viewed the illuminated area near one edge of the kinescope and about 2 inches above it. The result was reasonably uniform optical pickup from the entire area, with some small improvement being obtained by the use of a 6- by 1-inch mirror placed near the edge opposite the vicinity of the guide funnel entrance.

With respect to the problem of signal pickup, it was suggested that the cover glass, or some other transparent plate placed on the film, might be used to convey a fraction of the light to pickups along the edge of the plate. Both lead glass and Lucite were tried and found unsatisfactory. The best results with respect to pick-up efficiency were obtained when the surface next to the film was sand blasted or etched, thus permitting light to be scattered into the plate, and propagated to the edges with relatively few internal reflections. However, the etched plates were unsatisfactory for purposes of viewing the film. When plates with smooth surfaces were employed, propagation to the edges required too many partial internal reflections to be useful.

Among the system problems not to be overlooked is the potential difficulty with the cathode-ray tube. Although no difficulties arose due to the CRT during the breadboard experiments, there are several possible problems with currently available cathode-ray tubes, e.g., obtaining a tube with a flat-face that will be non-browning and incorporating X-ray shielding. These problems have been investigated, and the results of the investigations are given in paragraph B.4.

2. Isotropic Scanning

a. Purpose for the Investigation

The breadboard models constructed for the directly viewed CRT used the standard broadcast television scanning pattern of 525 lines, interlaced 2 to 1, with a 60-cps field rate and 30-cps frame rate. Undesirable flicker and unidirectional scan effects were noted. It was decided to investigate experimentally the use of isotropic scanning to eliminate these two effects.

b. Experiments

Two free-running triangular wave generators were constructed, and deflection circuitry was provided to operate a 17QP4B kinescope in the isotropic-scanning mode. The triangular wave generators were made to operate between 5 to 12 kilocycles. The pattern obtained when both oscillators are at the same frequency and 90° out of phase is shown in Figure 2. When both oscillators are in phase, the pattern is a diagonal line; when both oscillators are 180° out of phase the pattern is the opposite diagonal, as shown by the broken lines in Figure 2. Thus, when the frequency difference between the oscillators is 1 cps, the pattern is a pulsating rectangle which grows from a diagonal (a degenerate form of the rectangle) to the square, shrinks to the opposite diagonal, and back again to the original diagonal within a period of 1 second. As the frequency difference is increased, the rectangle scan occurs more rapidly, until it is no longer resolved by the eye, and a uniform raster of light is seen with no flicker visible at a difference frequency of 60 cps.

However, the triangular wave frequencies cannot be made arbitrarily low even though the difference frequency is satisfactorily high. For example, if frequencies of 60 and 120 cps were chosen, the result would be a 2 to 1 pattern as shown in Figure 3. This is, of course, much too coarse a pattern to be useful. Frequencies of 61 and 120 cps would result in a 1 cps beat with the 2 to 1 pattern. When the frequencies are in the neighborhood of 10 kilocycles with a 60 cps difference, satisfactory operation can be obtained. At 10-kilocycle frequencies, however, the spot speed is about 1.5 times faster than that required for conventional television scan rates with equal raster sizes. The higher spot speed requires wider bandwidth in the circuitry and faster phosphor decay for equal performance. It was decided to attempt a semi-random mode of scan to evaluate whether lower spot speeds could be employed, while avoiding any relatively coarse pattern (such as 40 to 41 for example) persisting for a sufficiently long time to be objectionable. Accordingly, the oscillators were set at 5 kilocycles nominally, but each oscillator was independently frequency modulated at about a 1-kilocycle rate. The resulting patterns were entirely unsuitable.

The following arrangement proved to be satisfactory. Two frequency-locked oscillators were built to operate at frequencies of 10,500 and 10,560 cps. These oscillators were locked to the 60 cps power line with frequency dividers of 175 and 176, respectively. The scan pattern was 175 to 176 which is unresolved by the eye in the defocussed spot. The 60 cps frame rate produced no visible flicker even at high intensities of over 1000 ft-lamberts.

A block diagram of the synchronizing signal generators is shown in Figure 4.

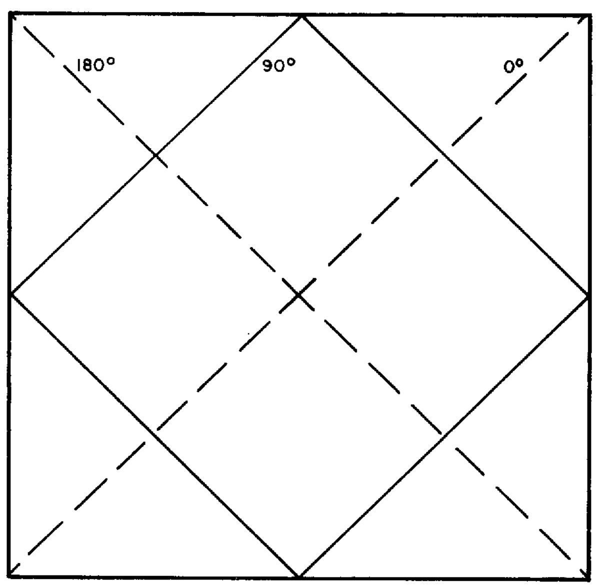

Figure 2. Isotropic Scan at Equal Frequencies for Various Phases

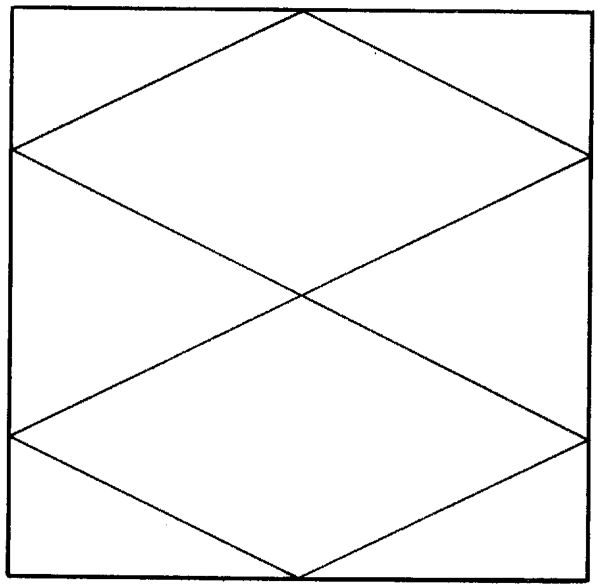

Figure 3. A 2-to-1 Isotropic-Scan Pattern

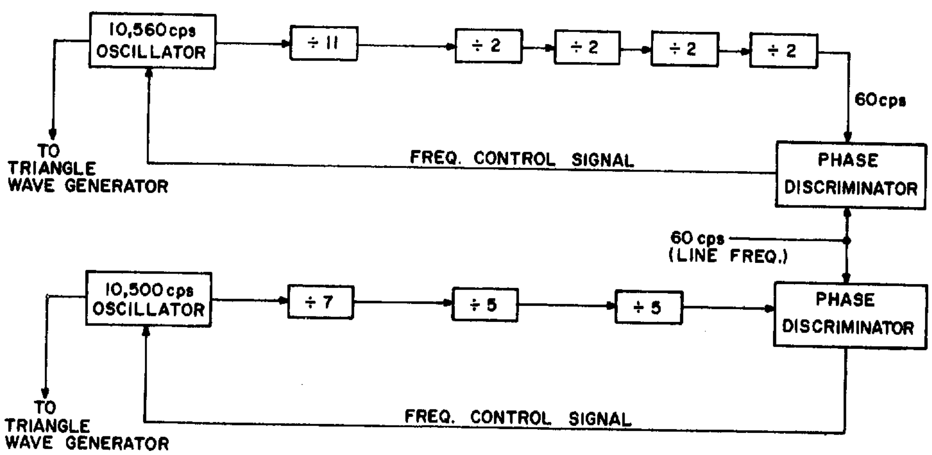

Figure 4. Synchronizing Signal Generator, Block Diagram

Schematic diagrams of the 10.5 and 10.56 K C/S synchronizing signal generators are shown in Figures 5 and 6, respectively.

A schematic diagram of the triangular wave generator, which is identical for each channel, is shown in Figure 7.

3. Investigation of Spot-Size Reduction Possibilities

One of the results desired from a modulated-light film viewer is the reduction of a large-area contrast without reduction of fine-detail contrast; in this manner, the relative contrast of the fine detail is enhanced.

A generalized curve of contrast vs. spatial frequency for a transparency viewed with unmodulated light is shown in Figure 8(a), Curve A. If the same transparency is viewed with light having a modulated component such as that shown by Curve B of Figure 8(a), the resultant apparent film response will be that of the crosshatched curve, also shown in Figure 8(a). Relative contrast at high and mid-frequencies is increased with respect to low-frequency contrast, which appears to be the desired condition for routine scanning and viewing under low magnification. The upper-frequency limit of Curve B is determined primarily by the spot size of the modulated illuminating light. For medium- or high-magnification viewing, the mid-frequencies appear as low frequencies, and the low frequencies are not seen at all.

Hence, if the modulation is to be effective, for increasing relative contrast of high-frequency information under conditions of large magnification, the spot size must be reduced to permit a modulation characteristic, as shown in Figure 8(b), Curve C.

It should be emphasized that what is demonstrated in principal in Figure 8(b) may be very difficult to realize in a practical viewer, particularly if the format is large.

The spot size obtained in the breadboard equipment is determined primarily by the thickness of the CRT faceplate. As mentioned above, this results from the need for a diffuser on the outer surface of the CRT. The effect of this is shown in Figure 9(a), where it is assumed that the light is being emitted from a point on the phosphor. The light from the point will be contained within a cone having a half-angle of 40°, as shown, this being the critical angle for glass, with the index of refraction of 1.55. When seen through the diffuser, the spot has a profile shape approximately as shown in this Figure. The half-amplitude spot diameter has been found to be about 0.75t, as shown in Figure 9(b).

Several factors contribute to the increased spot size. The light emission from the phosphor is not from a point source as assumed, the critical angle is greater than 40°, and some light arrives at the diffuser after multiple reflections.

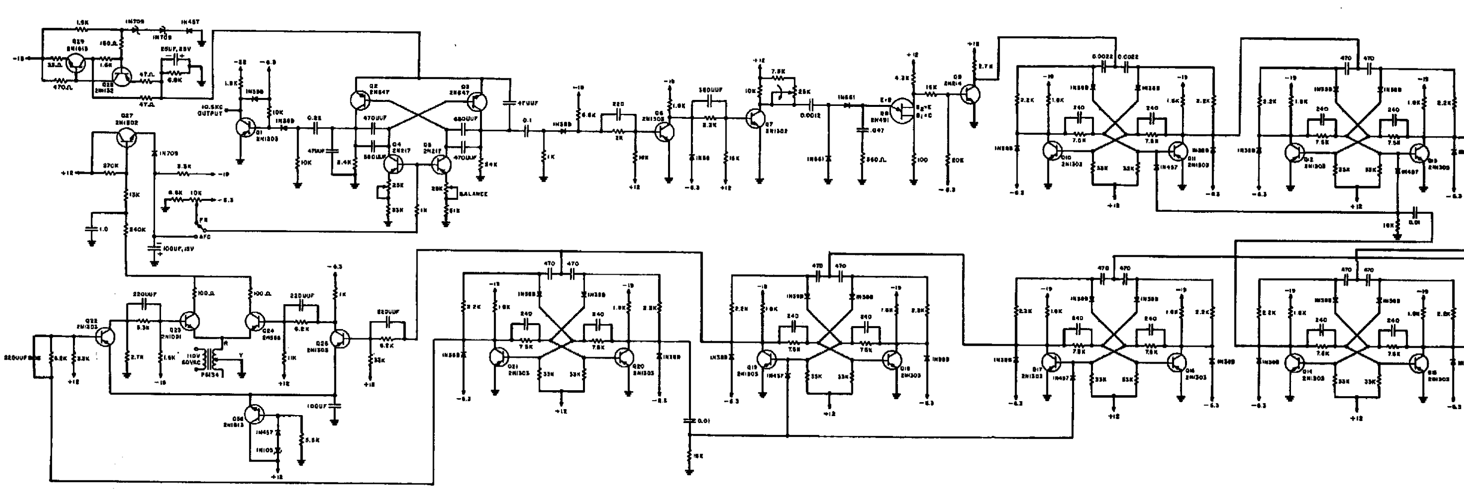

Figure 5. 10.5-Kilocycle Synchronizing Signal Generator, Schematic Diagram

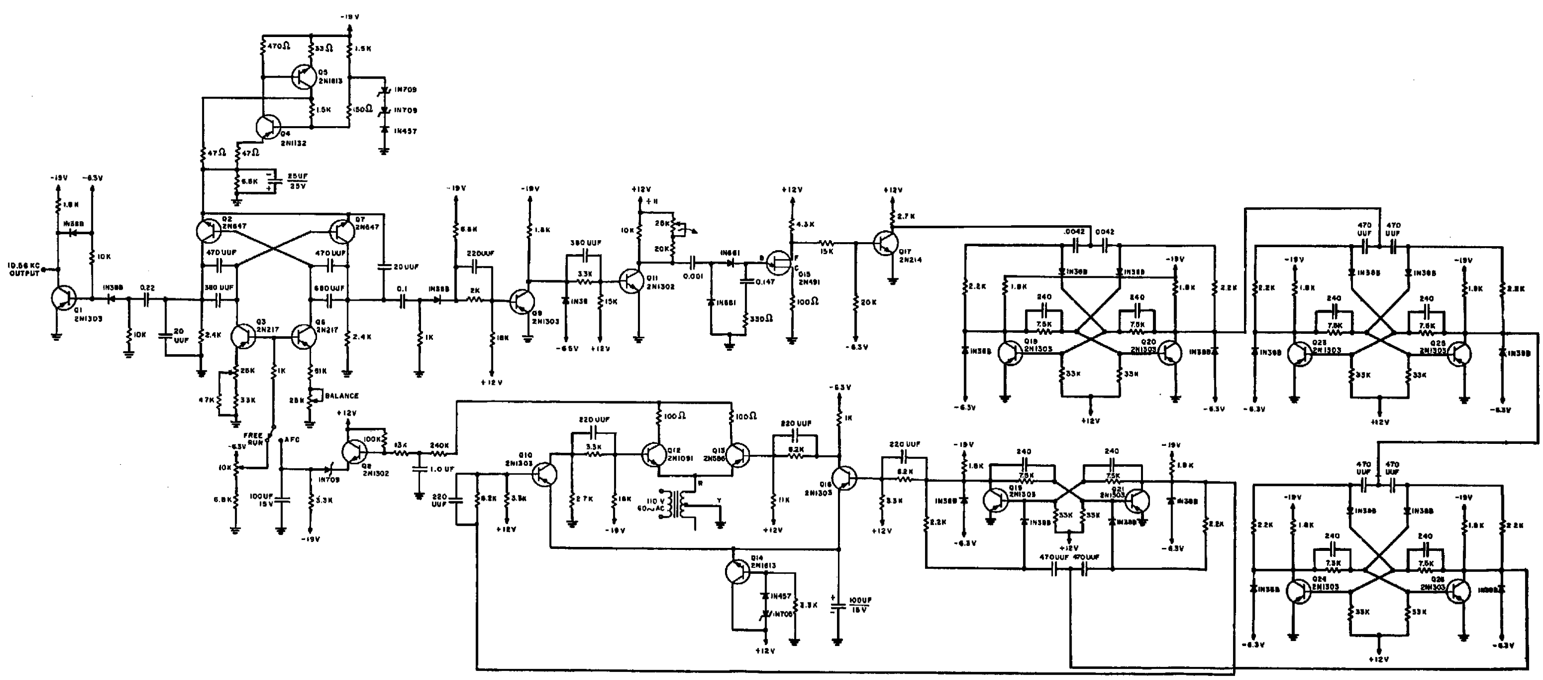

Figure 6. 10.56-Kilocycle Synchronizing Signal Generator, Schematic Diagram

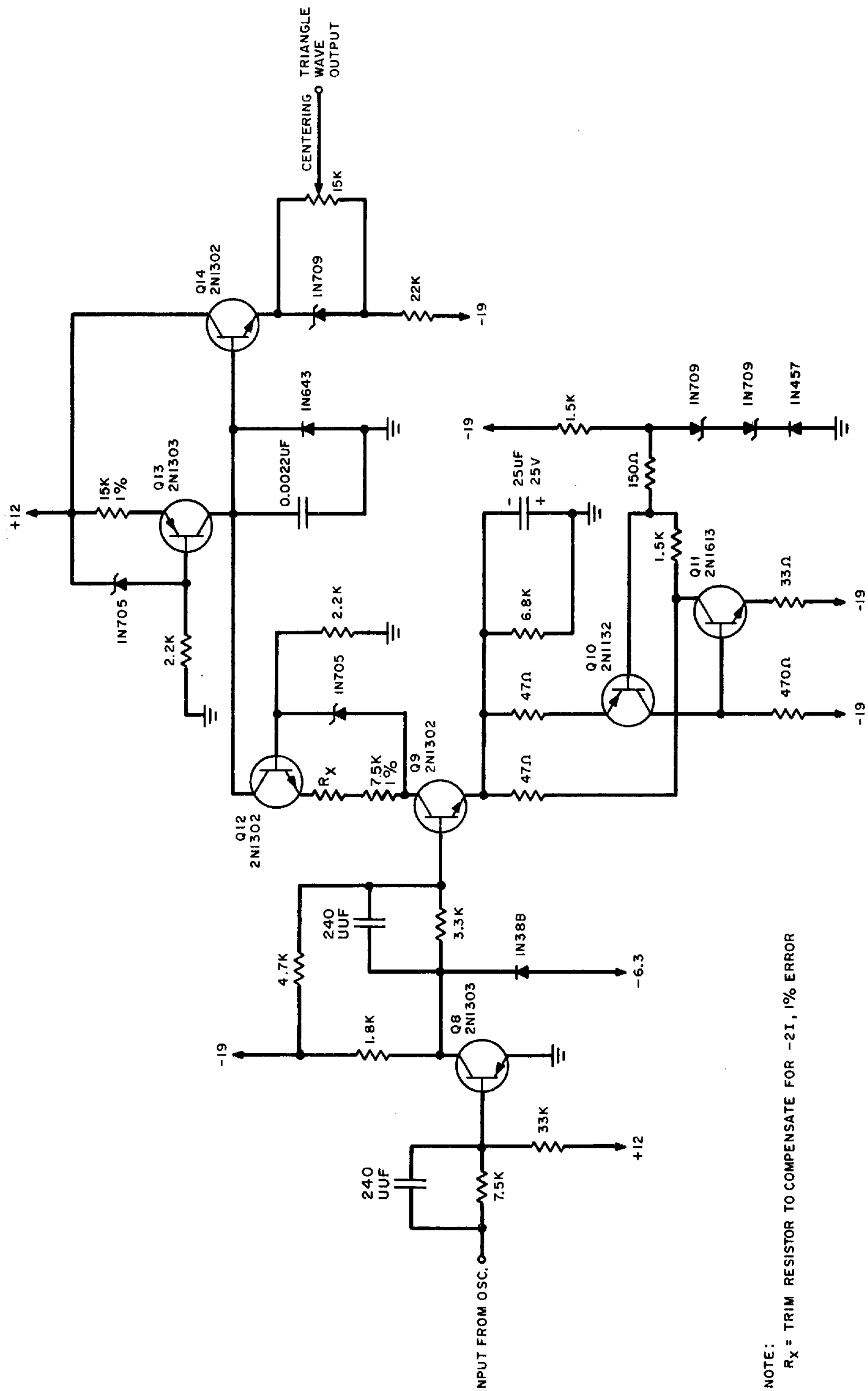

Figure 7. Triangular-Wave Generator, Schematic Diagram

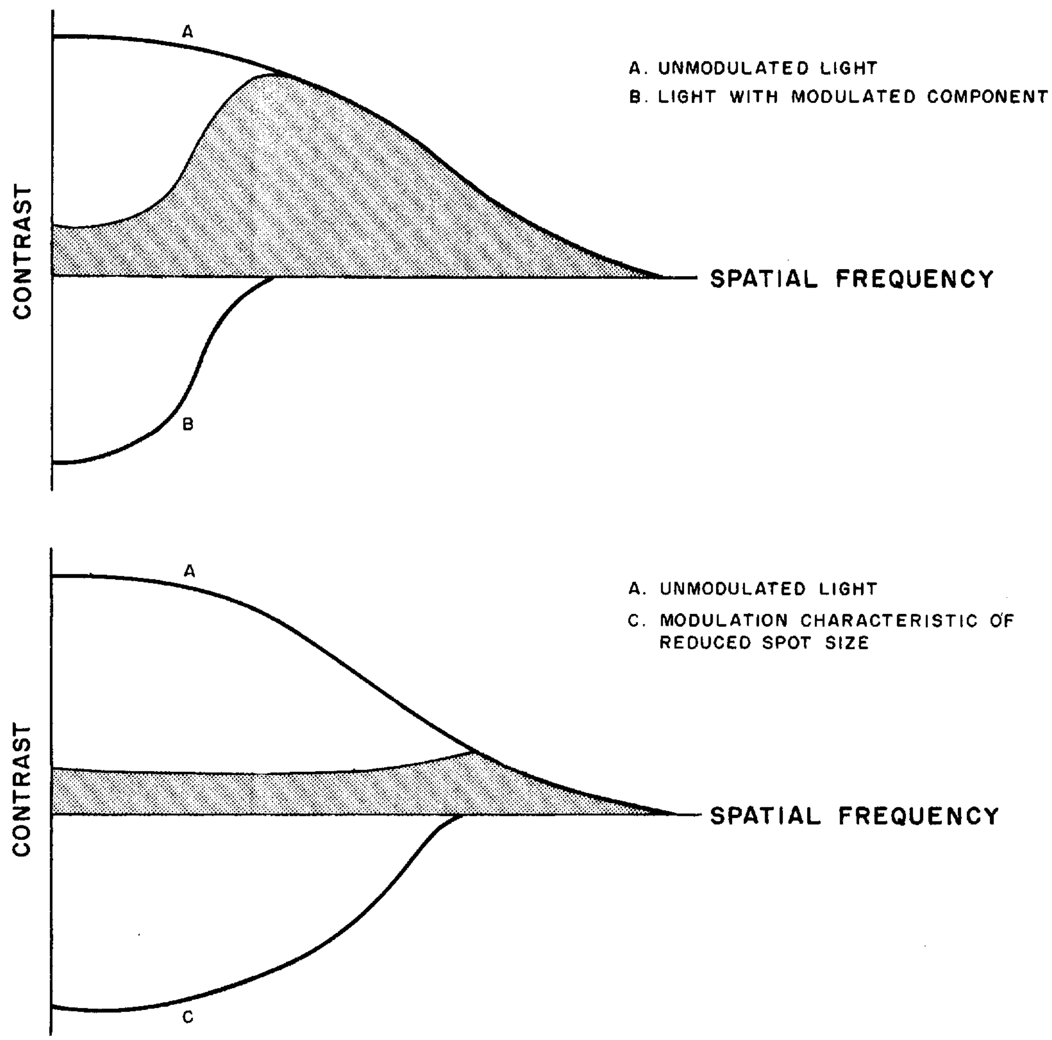

Figure 8. Generalized Curves for Contrast vs. Spatial Frequency

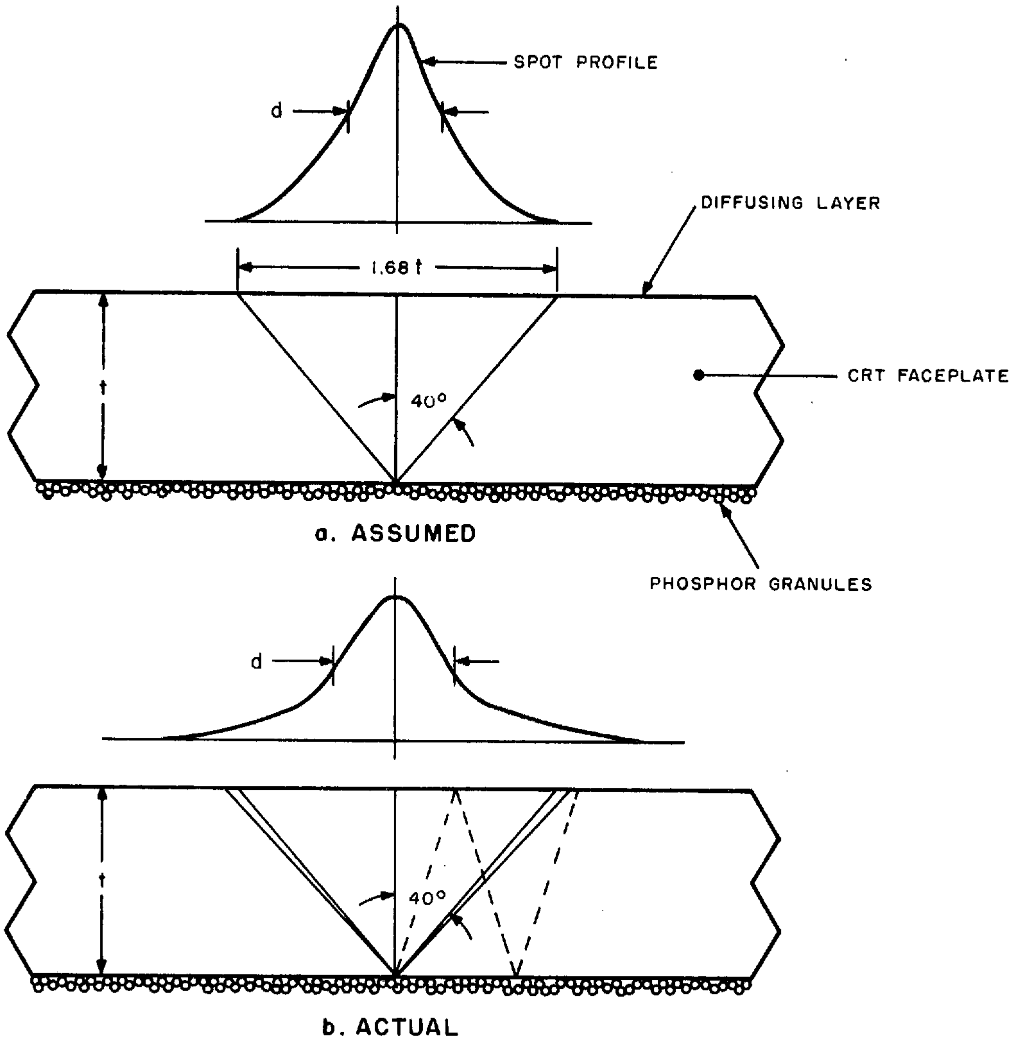

Figure 9. Profile of Spot When Seen Through the Diffuser

Use of a fiber-optic faceplate would permit spot-size reduction to the dimensions of the order of the fiber size. Mosaic Fabrications, Inc., of Southbridge, Mass., can supply a 9- by 9-inch faceplate for $6000.00. A faceplate segmented of 9 pieces of 3- by 3-inches each could be made for $4000.00. To the cost of the faceplate must be added the expense of sealing the faceplate onto a bulb. Investigations have not uncovered any instance where sealing of a faceplate of this size has been attempted. There is no firm assurance, therefore, that the sealing operation would be successful. Consequently, this otherwise ideal solution is not recommended in the early stages of development.

A less attractive technique that can result in reduced spot size is the use of a special glass having an irreversible photochromic characteristic, whereby the glass is rendered opaque (with proper processing) where exposed to light. A layer of this glass formed to have transparent channels would collimate the light and permit a reduction in spot size. If the collimated light were to have a half-angle of 5°, more than half of the light emitted would be absorbed in the opaque glass. This scheme did not appear attractive, and was not studied further.

It therefore became obvious that for the directly viewed CRT light table, a fiber-optic faceplate would be required for a significant reduction of the spot size demonstrated in the breadboard equipment. Operation with the relatively large spot size, however, does appear to provide sufficient modulation to be useful under certain operating conditions.

4. Problems with Cathode-Ray Tubes for Application in the Directly Viewed CRT System

Cathode-ray tubes that are perfectly suitable for this application are currently not available. The ideal CRT would be a flat-faced tube utilizing non-browning fiber optics and incorporating X-ray shielding. The discussion that follows presents both the problems in achieving the ideal tube and possible intermediate approaches.

a. Achieving a Flat-Faced CRT

As mentioned earlier in this discussion, a truly flat-faced tube in a large format is not commercially available. It is recognized, however, that the tube made by the Rauland Company* can be made flat by cementing a flat section onto the spherical face of the tube. Unfortunately, the spot size is further increased because of the increased overall thickness of the faceplate.

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* Described in footnote, paragraph B.1 of this section.

25X1 The [redacted] was requested to estimate the feasibility and cost of construction of a cylindrical faceplate having a radius of curvature greater than 100 inches. For small quantities, the faceplate would be made by sagging plate glass into a cylindrical mold, cutting a section out of a standard faceplate, and inserting the special plate. A fit seal would then be made. The engineers at [redacted] 25X1 would give no firm assurance that the sealing operation would be successful and 25X1 the quoted price for two units was [redacted] The construction of pressmolds for an entire faceplate using non-browning color-tube glass* would cost more 25X1 [redacted] Kinescope bulbs (J133 C/E) having a cylindrical faceplate of ordinary glass are a stock item made by Corning. This bulb has a faceplate with 27-inch radius of curvature. It would seem reasonable to make the bulbs in this mold with the non-browning color tube glass, however, the glass is in one factory and the molds in another, and a setup charge of $30,000.00 is involved to bring the two together.

b. Non-Browning Glass

Two types of glass browning are encountered: electron browning and X-ray browning. Electron browning is shallow, not highly sensitive to accelerating potential, and is non-permanent. Bleaching takes place in a few hours at room temperature and is significantly accelerated with even a moderate temperature rise. X-ray browning, however, is more lasting, is voltage sensitive, and extends through the thickness of the glass.

Non-browning glasses have been developed for use in kinescopes to be operated at accelerating potentials greater than 22 KV. The only large kinescopes made with non-browning glass are color picture tubes. Monochrome television picture tubes are operated at 20 kilovolts or less. However the need for non-browning glass for use with 30-kilovolt accelerating potential may not be compelling. The breadboard model was operated for an estimated 150 hours at 30 kilovolts and at an average brightness of about 200 foot-lamberts with no observable browning.

c. X-ray Shielding

When a CRT is operated at accelerating potentials higher than 22 kilovolts, and X-ray hazard can occur, and personnel working at close range must be protected. Ideally, this would be most conveniently accomplished by making the faceplate of lead glass which has excellent X-ray shielding properties. Consultation with [redacted] has disclosed, 25X1 however, that glasses with good X-ray shielding properties are highly susceptible to browning, and are not entirely suitable for use with fiber optics. Satisfactory X-ray shielding for personnel can be readily obtained with as little as 1 millimeter thickness of lead glass which may be incorporated as a bonded cap on the faceplate, or in a separate plate over the film.

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* The reasons for stipulating color-tube glass is given in paragraph B.4.b.

C. PROJECTION CRT SYSTEM

A projection system in which light from the CRT is imaged onto the film plane was investigated prior to the studies performed on the directly-viewed CRT system. Initial studies of the projection CRT system showed that all the requirements listed in Section II could be met, except that the maximum obtainable average brightness was 500 instead of 1000 foot-lamberts.

1. System Concept

Viewing illumination would be provided by a 7NP4 projection CRT in conjunction with a 26-inch-diameter Schmidt optical system, as shown in Figure 10. Frequency-sensing illumination would be provided by a second CRT, a 5ZP15. The frequency-sensing spot must be finely focussed to provide maximum resolution, while the illuminating spot must be relatively large so that no scanning-line structure would be visible. The P4 phosphor of the main illuminator emits a white light and has a medium persistence. The P15 phosphor of the frequency-sensor CRT has a very short persistence and emits light with a sharp peak at 3900 Angstroms and a broader peak at 5000 Angstroms that could be filtered out, rendering the light invisible to the photo-interpreter. A photomultiplier tube would be used to sense the transmitted illuminating light to provide the negative feedback signal so that the contrast will be compressed. A second photomultiplier, sensitive only to the ultraviolet light from the frequency-sensing spot, would provide a signal that could be processed to yield information as to the spatial frequency, which would in turn be used to modulate the main illuminating spot to increase illumination by a factor directly proportional to the spatial frequency. It should be noted that the two spots must be superimposed at the film plane and scanned synchronously. Isotropic scanning would be employed to eliminate unidirectional effects.

2. Experiments

The following experiments were performed using a breadboard setup of portions of the system. Experimental equipment included a 20-inch f/0.8 Schmidt optical system, a five-inch projection CRT, horizontal-deflection circuits, and high-voltage power supplies. In addition, the following assemblies were built: vertical deflection drivers, photomultiplier pickup and Nuvistor cathode follower, phosphor-lag-correction video amplifier, and video-output amplifier.*

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* The deflection circuitry, amplifiers, photomultiplier pickup and power supplies were subsequently modified and used on the breadboard of the directly viewed CRT system.

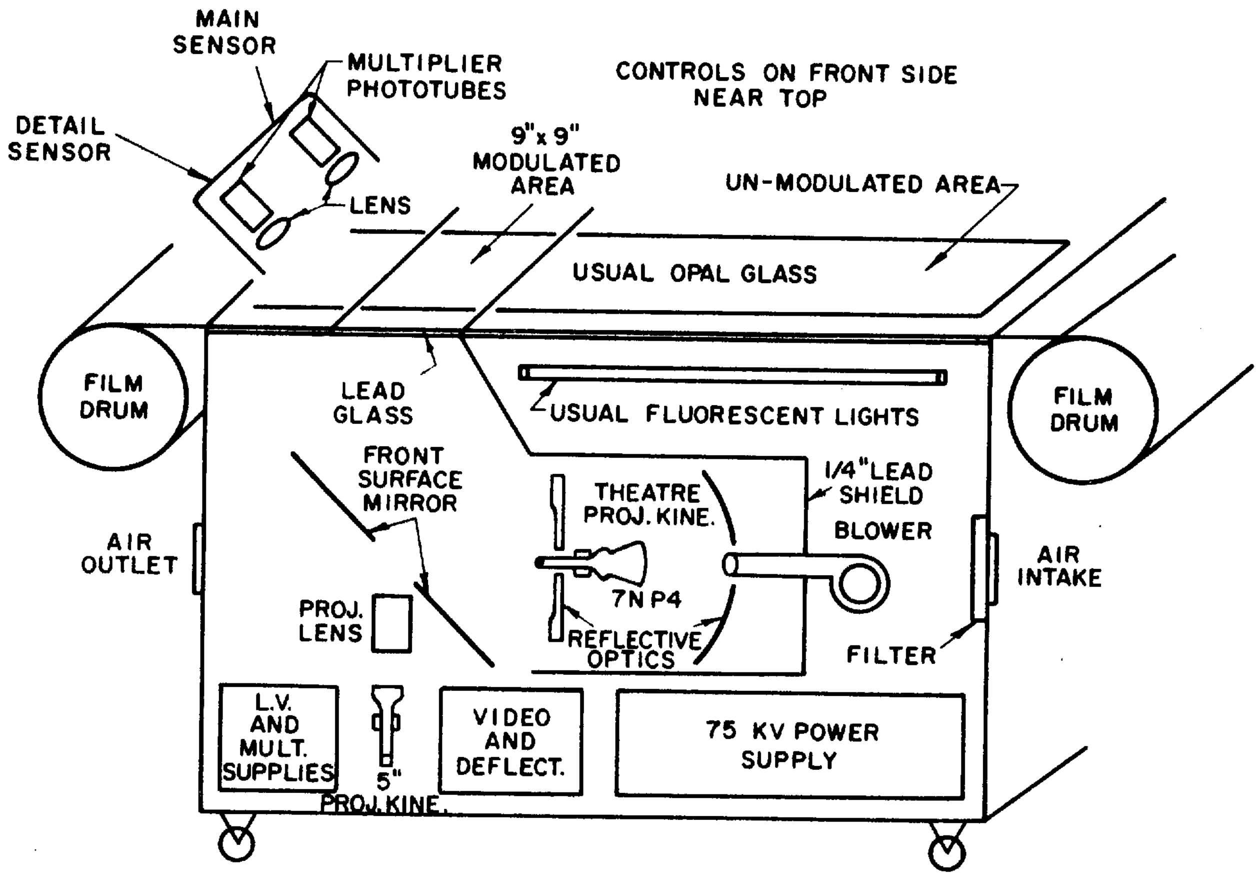

Figure 10. Modulated-Light Film-Viewing System Employing Projection CRT Light Sources

Each amplifier was made with a 20-megacycle passband in the expectation that the amplifiers might later be used for the high-frequency video requirements of the frequency-sensor channel, although, incorporation of this feature at the outset was not planned.

A transparency was laid over an opal glass diffusing screen at the focal plane of the optical system; with the photomultiplier pickup on the viewing side of the screen, the feedback operation was readily achieved. Minor problems were encountered with respect to loop oscillation resulting from improperly adjusted phase shift, which at first permitted a modulation contrast of only 5 to 1. The brightness, as expected, was only about 50 foot-lamberts, but it was adequate for feasibility studies.

It was considered desirable to be able to place the pickup on the illumination side of the screen rather than on the viewing side. The arrangment used to implement this technique is shown in Figure 11. Partially reflecting mirrors of various reflectances were tried, but the results were disappointing. The principal deterrent to this scheme was the diffuser, which was essential for viewing purposes, but decreased the feedback modulation to an unusable amplitude. The following analysis serves to explain these findings. A light flow diagram for the system is shown in Figure 12, where

I_i	is the light incident on the sandwich,
I_p	is the light returned to the photomultiplier,
I_t	is the light rransmitted to the observer,
T	is the transmittance of the film,
R	is the reflectance of the mirror,
KG	is a conversion factor which relates conversion of I_p to I_i in which G is the amplifier gain and is taken as positive, i.e., no phase reversal, and
I_o	is the unmodulated portion of I_i.

From the above,

$$I_i = I_o - KG\,I_p$$

$$I_t = (I-R)\,T\,\frac{I_i}{2}\sum_{n=o}^{\infty}\left(\frac{RT^2}{2}\right)^n \qquad (1)$$

$$= \frac{(1-R)\,T}{1-\frac{RT^2}{2}} - \frac{I_i}{2}$$

$$= \frac{(I-R)\,T\,I_i}{2-RT^2} \qquad (2)$$

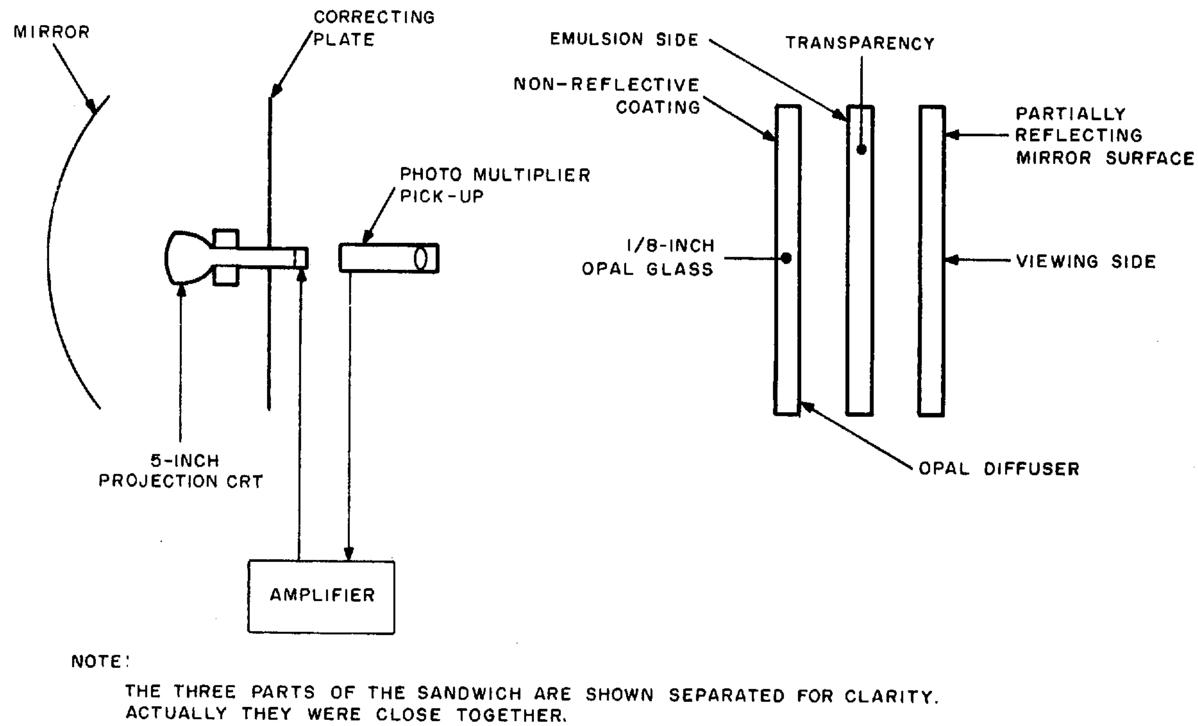

Figure 11. Test Arrangement for Photomultiplier Pickup on Illuminated Side of the Screen in the Projection CRT System

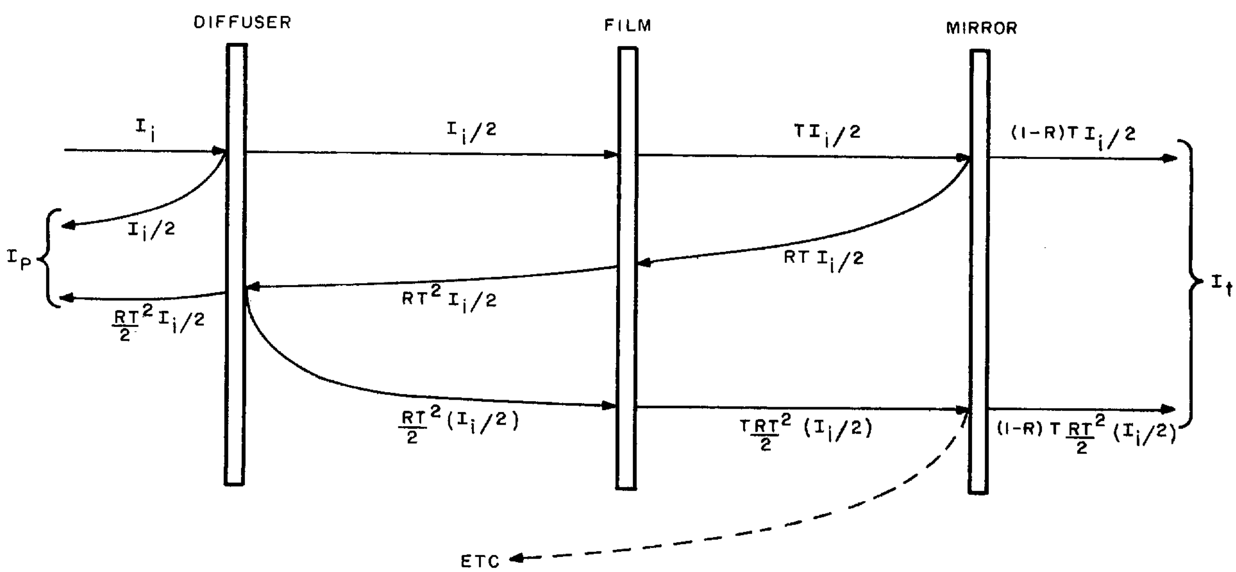

Figure 12. Light Flow Diagram

$$I_p = \frac{I_i}{2} \sum_{n=o}^{\infty} \left(\frac{RT^2}{2}\right)^n$$

$$= \frac{1}{1 - \frac{RT^2}{2}} = \frac{I_i}{2}$$

$$= \frac{I_i}{2 - RT^2} \tag{3}$$

The optimum case occurs when R = 1 for purposes of feedback, but R = 0 for purposes of viewing, which might be accomplished by using two-color light and a dichroic mirror.

When Equation (3) is evaluated at R = 1,

$$I_p = \frac{I_i}{2 - T^2}\ , \tag{4}$$

and from Equations (1) and (4),

$$I_i = I_o \left(\frac{2 - T^2}{2 - T^2 + KG}\right) . \tag{5}$$

However, for viewing purposes, R = 0. From Equations (2) and (5), evaluated at R = 0,

$$I_t = \frac{I_o}{2}\left[\frac{T\,(2 - T^2)}{2 - T^2 + KG}\right] . \tag{6}$$

Evaluating Equation (6) at T = 1 and T = 0.01,

$$I_{t\,(1)} = \frac{I_o}{2}\left(\frac{1}{1 + KG}\right), \tag{7}$$

and

$$I_{t\,(0.01)} \approx \frac{I_o}{2}\left[\frac{(0.01)\,(2)}{2 + KG}\right] . \tag{8}$$

Dividing Equation (7) by Equation (8) yields

$$\frac{I_{t\,(1)}}{I_{t\,(0.01)}} = 100 \; \frac{2 + KG}{2 + 2\,KG} \tag{9}$$

When Equation (9) is evaluated at G = 0, the no feedback condition, the expected ratio of 100 results. When Equation (9) is evaluated at $G \rightarrow \infty$, which is the maximum contrast compression to be expected for this system, the ratio is 50. A contrast compression of only 2 to 1 has been obtained.

The above analysis is predicated on a single-beam two-color-phosphor CDT in which both colors are modulated by I_p. If, however, the light of color to generate I_p were unmodulated, and the signal component of I_p were used only to modulate the viewing light, e.g., by the use of two kinescopes in a manner similar to that shown in Figure 10, then large values of contrast compression could be obtained. Feedback stability criteria would not prevail since the feedback loop would not be closed, and consequently, either contrast compression or contrast stretch could be obtained. The principal limitation to be encountered would be signal-to-noise considerations resulting from poor modulation in the feedback signal under conditions of low transmittance.

D. NON-CRT TECHNIQUES

1. Scanning-Light Beam

Consideration was given to a system that would employ a scanning light beam generated and deflected by means other than by a CRT. The basic elements required for such a system are:

1. Light source,
2. Light modulator,
3. Deflection system, and
4. Imaging system.

A laser, would be particularly well suited as a light source, because of its high brightness and well-collimated beam. The recently developed argon laser emits at six or seven different wavelengths, producing a white-appearing light. Arc lamps on other high-intensity light sources could also be used by employing the proper collimators.

The problems with using a light source of either type is the difficulty encountered in modulating and deflecting the beam. Light modulators of various types were reviewed, including Kerr cells, their solid-state equivalents, and ultrasonic light modulators. Direct modulation of the source was also considered. The modulation bandwidth required is 0 to 2 megacycles. The Kerr cell and linear electro-optic solid-state cells (of which KDP is the best developed) require voltage swings of the order of thousands of volts for useful modulation, and cell dissipation is such that overheating results from continuous operation without special cooling. The recently developed family of square-law electro-optic cells (of which the best developed in KTN*) are much better in this respect. Useful modulation is obtainable with voltage savings of tens of volts, and cell dissipation ammounting to milliwatts. However, there is a strong wavelength dependence of the electro-optic effect in the range from 0.4 to 0.7 microns, which makes this material unsatisfactory for white light. The ultrasonic cells can be made to operation with about 70- to 80-percent loss of light. Input power requirements are in the range of hundreds of watts.** Modulation of a gas laser can be accomplished by amplitude modulation of the pumping power, but it is limited to a few hundred kilocycles per second because of the relatively long lifetime of excited states required for laser operation.

Beam deflection can be accomplished by mechanical techniques, and by electro-optic cells.*** The latter are as yet insufficiently developed for application and suffer from wavelength dependence of the electro-optic effect, as noted above. The mechanical techniques are relatively inflexible with respect to scanning size and pattern requiring extremely precise construction and very high speeds of mirror or slit rotation.

In summary, it was considered that while a scanning-light-beam system might be designed to operate with existing components and techniques, the cost would be high and the performance would be unsatisfactory. No experimental work was performed in this area.

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* J.E. Geusic, S.K. Kurtz, L.G. Van Uitert, and S.H. Wemple, "Electro-optic properties of some ABO_3 Perovskites in the Paraelectric Phase," Vol 4, No. 8, 15 April 1964.

** "Theoretical and Experimental Investigation of Photocbromic Memory Techniques and Devices," <u>ASD Technical Report 61-70,</u> prepared for the Aeronautical Systems Division by National Cash Register Company, Hawthorne, California, issued Dec. 1961.

*** J.E. Guesic et. al., cited previously, and also W. Kulcke, T.J. Harris, K. Kosanke, and E. Max, Journal of Research and Development, IBM, 8, 64 (1964)

2. Photochromism Technique

A photochromic material is one which is normally transparent, but darkens upon irradiation by light. An ideal photochromic material, if one were available, would readily permit realization of the requirements for illumination level and contrast compression. Also, flicker and scan problems would be absent. However, the requirement that the modulation of the illumination be directly proportional to the spatial frequency implies that the spatial-frequency content of the film must be measured automatically by the system from point to point. This measurement would require a sequential sampling process, i.e., scanning. Furthermore, a second scanning beam would be required to modify the properties of the photochromic material to permit modulation of the transmittance of the photochromic material as a function of the spatial frequencies detected by the sampling process. Hence, even with a semi-passive system based on photochromism, two scanning processes would be necessary.

In addition, the control of size and position of the modulated-light area is not readily achievable with a system of this type. Finally, ideal photochromic materials are not available. The principal defects of existing materials are (1) low sensitivity, particularily to visible wavelengths, (2) fatigue, and (3) excessive lag*.

* National Cash Register Company Report cited previously.

SECTION IV
CONCLUSIONS AND RECOMMENDATIONS

The efforts in this study have been directed primarily toward the development of a modulated-light viewing system, in which the principal purpose of the modulated illumination is achievement of reduction in large-area contrast, and hence a relative increase of contrast at higher spatial frequencies. Other desirable features which should be included in the light table include a facility for varying the amount of modulation and brightness of the illumination and the capability to vary readily the size and position of the illuminated area.

Photochromic materials, a scanning light beam, and projection and directly-viewed CRT systems have been considered for this application.

Available photochromic materials were found to suffer from lack of sensitivity, fatigue, and lag. Independent control of the degree of modulation and brightness does not appear achievable, and control of size and position of the illuminated area is cumbersome.

The scanning-light-beam system presents serious problems in modulation and deflection with presently available electro-optic components. A mechanically scanned system is highly complex and cumbersome if the desired flexibility is to be incorporated.

Hence, the choice is narrowed to the two types of CRT systems considered, which have in common the ready control of (1) size and shape of the illuminated area, (2) intensity of illumination, and (3) degree of contrast compression. Weighing the relative merits and costs of the projection CRT and directly viewed CRT systems leads to the recommendation of the latter for this application. A brief comparison of the features offered by the two systems as they apply to a small light table are given in the table in Section III. The selected system has been discussed in detail in the text. For convenience, a brief summary of the equipment, as recommended, is given in the following paragraphs.

The table would be placed on a console 66 inches wide × 25-1/2 inches deep × 36 inches high, which contains all power supplies and other electronic components. The table top, which is tiltable to 45°, supports the CRT, film reels, microscope carriage, and an auxiliary unmodulated area of illumination. The CRT, and film transport are rotatable through 360°. The CRT proposed for initial system development is a modified 17QP4 that has a faceplate with a 27-inch radius of curvature. This tube will accommodate an illuminated area of 9 × 12 inches. A lead glass safety plate over the CRT faceplate is provided for X-ray protection. Optical pick-up for the feedback loop is accomplished by a bent Lucite light-funnel and a photomultiplier tube. The scan pattern proposed is the isotropic scan provided by triangular deflection waves at 10.50 and 10.56 kilocycles. The flicker rate is 60 cps. Peak brightness at the film plane is 1000 foot-lamberts. Contrast compression will be 30 to 1 for a density step of 0 to 2. The operating controls consist of:

1. Brightness,
2. Contrast compression gain,
3. Height and width of illuminated area, and
4. Position control of illuminated area.

A system has also been conceived to provide contrast stretch in small areas. This scheme is directed toward the requirements of the large table in which detailed inspection is performed with relatively high magnification. This conceptual system is recommended for future study.*

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* A proposal covering the recommended directly-viewed CRT system which was submitted to the U.S. Government, December 23, 1964, No. 64031-B, also includes a detailed description of the conceptual system for contrast stretch in small areas. 25X1

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